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LUBBOCK DEPT OF ELECTRICAL ENGINEERING

J F MALKUP ET AL. 30 MAR 87 AFOSR-TR-87-0614

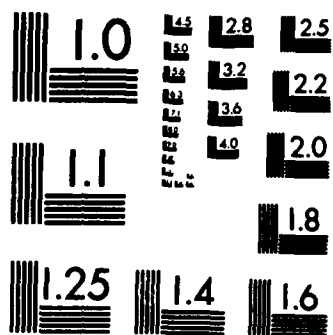
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SPACE-VARIANT OPTICAL SYSTEMS

Annual Technical Report

on

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(Nov. 30, 1985 - Sept. 30, 1986)

by

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Co-Principal Investigators

March, 1987

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ABSTRACT

Analytical and experimental investigations of 1-D and 2-D coherent and incoherent space-variant optical processors have been conducted. Areas investigated have included: (1) bilinear transform implementations using AO processors; (2) optical polynomial processing; (3) window-programmable image processors; (4) optical multistage interconnection networks; and (5) a 2-D Clos interconnection network.



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RESEARCH OBJECTIVES

The major research objectives during the second funding period (10 months) of the grant (November 30, 1985 - September 30, 1986) have been to perform both analytical and experimental work on optical implementations of space-variant optical processors. The major areas of investigation have been (1) implementations of the bilinear transform using acousto-optical processors; (2) additional applications of the bilinear transform including optical polynomial processing and window-programmable image processors; (3) optical multistage interconnection networks and (4) a 2-D Clos optical interconnection network. Details are provided in the following sections.

SUMMARY OF RESULTS

Since most of the results obtained under the grant are promptly submitted for publication, and also presented at national and international scientific meetings, we will briefly summarize the major results obtained in this section, with references made to the appropriate publications, conference papers, and reports.

A. Bilinear transform implementations using acousto-optical processors.

A proof-of-principle experiment was set up and tested in which acousto-optical processors were used to perform general linear operations based on the bilinear transform [1]. A significant advantage of the system is that one basic system architecture can have many applications or perform different linear operations. To illustrate, consider the light incident on an acousto-optical (AO) cell as the first input $f'(x')$, and the electronic signal input to the AO cell as the second input, $f''(x'')$. By frequency modulation and spatial modulation of the AO cell, any combinations of two inputs are deflected to different output locations where masks (which determine the operations to be performed) are placed. Using a multichannel AO cell would improve

the space-bandwidth product characteristics. Binary masks were made for the proof-of-principle experiments. The mathematical applications possible with the system include inner product operations, convolution and arbitrary triple matrix-vector products. For future research, it would also be interesting to implement some of the other applications of the bilinear transform and use other types of masks such as holograms and three-level mask elements (1,0,-1).

B. Applications based on the bilinear transform

During this past year, we have investigated extensions of our previous work on optical bilinear processing, with special emphasis in the area of optical computing. This work was motivated by our earlier work on optical linear space-variant processing. It is also motivated by the extension of optical processors to include nonlinear operations. As a preliminary result, a general mathematical model was developed, several optical implementation techniques were designed, and a number of application areas were studied, including programmable optical interconnections [2], triple-product processing in logic design [3] and 2-D crossbars [4]. Due to the flexibility of the bilinear transform, two more applications have been investigated in the past year, as indicated below.

1. Optical polynomial processing [5]

With the motivation of extending bilinear operators to a more general class of nonlinear operators via a Volterra series (polynomial) approximation, optical polynomial processors [6,7] with high speed and throughput need to be investigated and implemented. We examined optical polynomial implementations using a factored representation so that presently known bilinear techniques can be employed. Since there are two inputs and one kernel in the generalized bilinear transform, the two inputs act as polynomial input variables and the elements in the kernel represent the coefficients of the quadratic polynomial. Thus higher order polynomial processing can be realized by iterating the bilinear transform.

A dual-LCLV system has been set up to form such a quadratic polynomial. Using electronic or optical feedback, a general optical polynomial processor is achievable. The work has been extended to perform bipolar complex analog and binary digital polynomial operations. The analog operations can be performed by using separate parallel channels for real/imaginary and positive/negative numbers. The concepts of systolic and wavefront processing can be used to implement binary digital polynomial processing.

At this stage, the polynomial system for digital processing has been set up and tested in the lab with good results.

2. Window-Programmable Image Processors

To solve the problem of implementing high speed processing of large amounts of data, such as 2-D or 3-D images, present electronic computers are limited due to their fundamentally serial nature. One approach to overcoming this problem is to use optical computing systems with the capabilities of parallel, high speed processing.

We designed an optical system, based on the bilinear transform, for processing 2-D images. In the area of linear, space-invariant image processing, the output images can generally be expressed as the convolutions of the input images and small window functions. In other words, the output image is equal to the summation of the shifted input images which correspond to the weights and locations of coefficients in the window. If we interpret one of the inputs in the bilinear transform as an input

image, the other one as a window and the kernel as shifted gratings, then a convolution-based image processor can be looked at as a bilinear processor. Experimental results were obtained demonstrating bipolar two-level image processing where edge-enhancement was the application which was successfully demonstrated.

C. Optical Multistage Interconnection Networks [8].

This project was motivated by our 2-D optical crossbar implementations. Recently, a number of optical interconnection networks have been proposed and demonstrated such as crossbar networks [9] and perfect shuffle networks [10]. In spite of their feasibility, however, these networks only deal with 1-D data and ignore the inherent 3-D characteristics of optical systems. Another major problem is that although crossbars are ideal networks for interconnections, crossbar networks of large size are very difficult to implement either in optics or electronics. An alternate approach is to design multistage networks, with each stage having a number of crossbars of small size. Based on the above noted reasons, we believe the continued investigation of 2-D optical multistage interconnection networks (MINs) is very important.

We have proposed the framework of a 2-D MIN and explored the advantages and applications of the 2-D perfect shuffle network, including (1) the quaternary number representation of the 2-D perfect shuffle network, (2) reduction of the number of stages for realizing all permutations between inputs and outputs, (3) implementation of a 2-D FFT, (4) bivariate polynomial evaluation and (5) matrix transposition. Also an experimental setup for a 2-D perfect shuffle demonstrated the simplicity of an optical implementation. We are definitely encouraged by the results obtained to date on this particular project and we believe that the further investigation of the 2-D MIN is of great interest in the field of optical computing.

D. A 2-D Clos Optical Interconnection Network [11].

The interest in devising a 2-D Clos network is due to its 3-stage layout and ability to implement 2-D crossbar networks of large size using a number of subcrossbars of medium size. The Clos network has the same characteristics as the crossbar network, but an important factor is that the number of switching elements has been reduced in the Clos network (10:1 for a 1000x1000 network, as compared with the crossbar network). The difficulty of determining routing connections, however, is a major problem to be overcome [12]. We have come up with a straightforward algorithm

to route the Clos network. This algorithm can be performed either by a uniprocessor or by parallel processors. Also the routing algorithm is not unique, and the possibility for alternative choices gives the routing algorithm an ability to tolerate faults.

We have demonstrated an optical implementation of the 2-D Clos network with good experimental results. A 2-D Clos network can also be used to realize 2-D neural networks, and furthermore, the neural connections are programmable. This will give neural processors the flexibility to perform more complex computations. We are presently looking into several of these issues.

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1. G. E. Spillman, Jr. "Bilinear Processing with Acousto-Optical Modulators," M.S. thesis, Dept. of Electrical Engineering, Texas Tech University, August, 1986.
2. S.H. Lin, T.F. Krile and J.F. Walkup, "Programmable Optical Interconnections Based on the Bilinear Transform," SPIE 625, 159 (1986).
3. S.H. Lin, T.F. Krile and J.F. Walkup, "Optical Triple-Product Processing in Logic Design," Appl. Opt. 25, 3089 (1986).
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5. S.H. Lin, T.F. Krile and J.F. Walkup, "Optical Polynomial Processing Based on the Bilinear Transform," (presented at the 1986 Annual Meeting, OSA, Seattle).
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9. A.A. Sawchuck, et al., "Optical Matrix-Vector Implementation of Crossbar Interconnection Networks," International Conference on Parallel Processing, St. Charles, IL, August (1986).
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11. S.H. Lin, T.F. Krile and J.F. Walkup, "A 2-D Clos Optical Interconnection Network," (presented at the OSA Topical Meeting on Optical Computing, Lake Tahoe, March 1987).
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RECORD OF JOURNAL PUBLICATIONS ON AFOSR 84-0382*

Journal Articles Published

1. V. Chandran, T.F. Krile, and J.F. Walkup, "Optical Techniques for Real-Time Binary Multiplication," Appl. Opt. 25, 2272-2276 (1986). Feature issue on Optical Computing: Part 2
2. S.H. Lin, T.F. Krile, and J.F. Walkup, "Optical Triple-Product Processing in Logic Design," Appl. Opt. 25, 3089-3096 (1986). Feature issue on Photonic Computing.
3. S.H. Lin, T.F. Krile, and J.F. Walkup, "Piecewise Isoplanatic Modeling of Space-Variant Linear Systems," J. Opt. Soc. Am. A-4, 481-487 (1987).

Journal Articles in Preparation

1. S.H. Lin, T.F. Krile, and J.F. Walkup, "A Generalized Bilinear Transform," (to be submitted to J. Opt. Soc. Am. A.).

* Papers appearing in published conference proceedings listed under "Interaction Activities".

RESEARCH PERSONNEL (1985-1986)

1. Faculty:

Dr. J. F. Walkup, Co-Principal Investigator, Horn Professor

Dr. T. F. Krile, Co-Principal Investigator, Professor

Dr. E. Bochove, Research Associate, Visiting Associate Professor

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3. Undergraduate Laboratory Assistants

B. Jones

V. Taylor

A. Ittycheriah

COMPLETED THESES AND DISSERTATIONS (1985-1986)

1. V. Chandran, "Techniques for Optical Binary Multiplication," M.S. thesis, Dept. of Electrical Engineering, Texas Tech University, December, 1985.
2. G.E. Spillman, "Bilinear Processing with Acousto-Optical Modulators," M.S. thesis, Dept. of Electrical Engineering, Texas Tech University, August, 1986.

INTERACTION ACTIVITIES (1985-1986)

Papers Presented at Major National Technical Meetings:

1. S.H. Lin, T.F. Krile, and J.F. Walkup, "Programmable Optical Interconnections Based on the Bilinear Transform," SPIE Proc. 625, 159-166, O-E LASE '86, Los Angeles, CA, Jan 1986.
2. T.F. Krile and J.F. Walkup, "Optical Systems Research at Texas Tech University," SPIE Proc. 634, Workshop on Opt. and Hybrid Computing, Leesburg, VA, March 1986.
3. S.H. Lin, T.F. Krile, and J.F. Walkup, "Two-Dimensional Optical Crossbar Based on Triple-Product Processing," J. Opt. Soc. Am. A3, 13, p. 80 (1986). (Paper presented at 1986 Annual Mtg., Opt. Soc. Am., Seattle, WA, Oct. 1986).
4. S.H. Lin, T.F. Krile, and J.F. Walkup, "Optical Polynomial Processing Based on the Bilinear Transform," J. Opt. Soc. Am. A3, 13, p. 96 (1986). (Paper presented at 1986 Annual Mtg, Opt. Soc. Am., Seattle, WA, Oct. 1986).

Other Interaction Activities:

1. Visited Prof. J.W. Goodman's research laboratory at Stanford University, July 1986 (J.F. Walkup).
2. Briefed Dr. Lee Giles in Leesburg, VA, March 1986 (J.F. Walkup and T.F. Krile).
3. Served as Chairman of IEEE Computer Society's Technical Committee on Optical Processing, 1985-1986 (J.F. Walkup).
4. Served on Education Committee of Optical Society of America (J.F. Walkup).
5. Visited Prof. R.J. Marks II and toured EE Dept. University of Washington, Seattle, WA, Oct. 1986 (J.F. Walkup, T.F. Krile, and S.H. Lin).

SIGNIFICANT ACCOMPLISHMENTS

1. Developed implementations of the bilinear transform using acousto-optical processors.
2. Investigated applications of the bilinear transform to optical polynomial processing.
3. Investigated window-programmable image processors based on the bilinear transform.
4. Investigated optical multistage interconnection networks and their applications.
5. Developed an optical 2-D Clos interconnection network. Demonstrated significant advantages of this type of multistage interconnection network as compared with crossbar networks.

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